Grass has much narrower stomata than drought-susceptible Dallis-Grass (*16, 47*). The preceding paragraphs of theory and observation awaken hope that these savings might be produced when willed.

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The Schools Lectures at the Royal Institution

The Institution provides a "repertory theater" of scientific experiments to be shown to young people.

Lawrence Bragg

The Royal Institution has a long and famous history. It was founded in 1799 by Count Rumford (Benjamin Thompson) at a time when there was a growing interest in Natural Philosophy and when "Literary and Philosophical Societies" were being formed in many centers. The founder, however, designed for it a structure more ambitious than that of other institutions, and although he failed to realize all his aims, his originality and foresight gave the Institution a unique character which it has retained. Not only was it to be a place where the intelligentsia would meet each other, hear discourses about science, and consult a library of scientific books and periodicals, it was also to include what we would now call a research center and a technical college. It was to have professors who, as well as informing the members of advances in science, were to do original work in the Institution's laboratories. It was to have classes for mechanics, because Rumford was convinced that they would do their work more efficiently and with greater interest if they knew something of the scientific basis of craftsmanship. One of Rumford's great interests was the application of scientific principles to objects of everyday use—grates, stoves, chimneys, ventilation systems, cooking utensils, clothing—and many of the things we take for granted nowadays—for example, the kitchen range, the pressure cooker, the coffee percolator, and the double-walled saucepan—are Rumford's inventions. His plans for training mechanics failed; he was before his time and was defeated by apathy and misunderstanding. On the other hand, his plan for combining the popular exposition of science with original research was gloriously successful, and these two functions have set the pattern for the Royal Institution for more than 150 years. For the first three-quarters of the 19th century, in the great days of Humphry Davy, Faraday, and their successors, it was the "center" for the physical sciences in Great Britain.

I have given this brief account of the history of the Royal Institution in order to sketch in the background for my description of the Institution's Schools Lectures. The Royal Institution is a private body, supported by its members' subscriptions, its endowments, and donations given by industrial and other bodies in recognition of its educational work. Being a private body, it is free to make experiments on its own initiative and to start new ventures.

The Christmas Lectures

One such venture, which has since become famous, was started in the year 1826. It was a course of six lectures "adapted for a Juvenile Auditory," given in the fortnight after Christmas. The Christmas Lectures have been held every year since then, except when interrupted by the two world wars. They are planned for young people between 12 and 17, though in the "Juvenile Auditory" all

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ages from 8 to 80 are often represented. By tradition these lectures are the great occasion for devising thrilling and novel experiments on a grand scale. Everyone knows about the Christmas Lectures and is willing to help. In particular, industrial firms will go to immense pains to provide something really exciting for the occasion. The lecturer gives his talks on some theme in the physical sciences, biology, or engineering and illustrates it with his demonstrations, though, it must be confessed, in choosing experiments their thrillingness is often given rather more weight than their precise appropriateness to the subject.

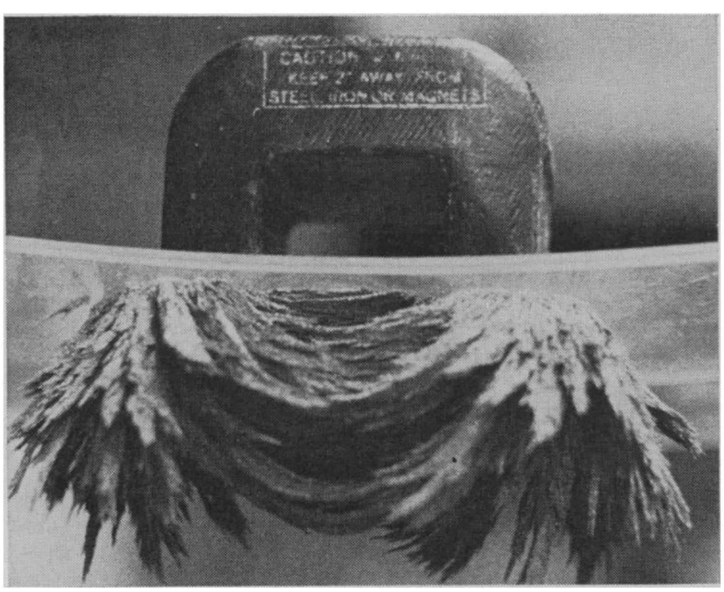
There have been two interesting features of these Christmas Lectures. The first is the number of people, in all walks of life, who say that their first realization of the interest of science came from their attending, as children, a Christmas Lecture at the Royal Institution. And invariably they say, not "He told us so and so" but "He showed us so and so." It is the experiment that creates the vivid and lasting impression. The second is the number of popular scientific books which have been based on the Christmas Lectures. The lecturer is generally invited afterwards to put his lectures into book form, and many—some 40 in all—of the best popular science books in Great Britain have originated in this way.

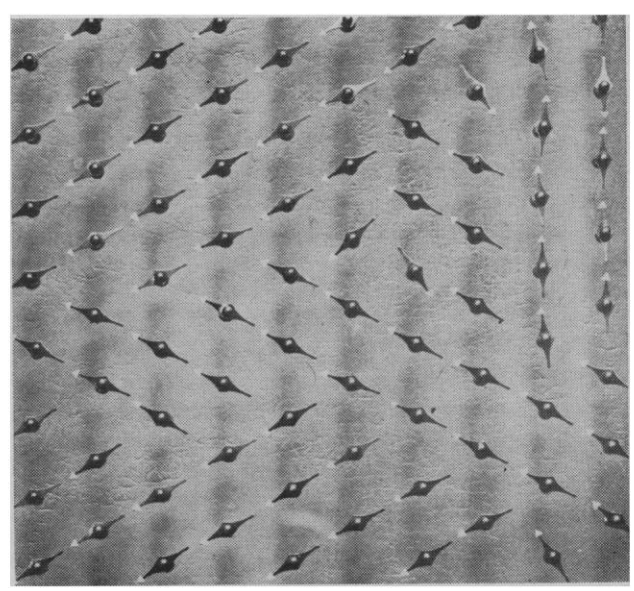
The Start of the Lectures

About 10 years ago the tradition of the Christmas Lectures suggested the idea of giving similar lectures to school pupils all year round. The Royal Institution has certain advantages in such a scheme. It has a lecture room that is very convenient for showing experimental demonstrations to a large audience. As so often happens, this advantage is as much the result of accident as of design. Rumford's idea was to have a theater with a lower auditorium to be occupied by the nobility and gentry and an upper gallery for his mechanics. The gallery had a separate exit to the street, so that the general herd should never meet the gentry and cause embarrassment on both sides. The result is an ideal semicircular auditorium, holding an audience of up to 500, in which every one has a clear and near view of the experiments conducted on the lecture bench and the large area of floor space around it. Again, the Institution is situated right in the center of London and so is easily accessible. Since England is a small country and the population around London is especially dense, about one quarter of the schools in England can conveniently send their boys and girls to an afternoon occasion at the Royal Institution.

The scheme was started in a small way at first, in collaboration with the science teachers of some of the London schools. They were invited to send their 6th-form science pupils (aged about 17) to lectures on quite general subjects such as electricity, magnetism, waves, and properties of matter. As the schools got to know about the lectures, there was a pressing demand for tickets and the attendance rapidly increased. At present about 22,000 tickets are issued annually. They are free and are distributed to the schools by the educational authorities in the different areas. Most of them go to pupils in the top science forms of the grammar schools, which teach science at a high level. Some go to younger pupils in the 14-to-15 age group, and recently the preparatory schools (up to 13 years) have asked for simple lectures suitable for these young people who are only starting their scientific training.

There are between 400 and 500 schools of grammar-school standing in the Greater London area, which extends into the adjacent counties, so each school can get some 40 tickets annually to give to its most promising and keen pupils. Although at present it is only the classes specializing in science which are served, there is just as great a need to serve the schools in which pupils are getting a general education, and it is hoped that the number of places can be doubled





Two demonstrations used in the Schools Lectures. (Left) Lines of force in three dimensions, shown by iron filings in the neighborhood of a strong permanent magnet. This demonstration, which is shown on closed-circuit television, has an advantage over the ordinary demonstration in which iron filings on a card are used, in that it shows the lines of force in all three dimensions. (Right) The Ewing model of a ferromagnetic material. The atoms are represented by a large number of very small compass needles; this illustration shows domains in the absence of a magnetic field. A number of experiments can be done with the model. If it is given a knock or otherwise agitated, the magnets set themselves in the direction of the earth's field; magnetization can be illustrated by stroking a magnet over the model; the agitation due to an irregularly moving magnet can be made to explain the Curie point.

in the near future; the limiting factor is not the demand for tickets, but the physical limitation on the number of experimental lectures which can be staged in the theater.

As I mentioned above, no charge is made to the schools for the tickets. The expense of organizing the talks is helped by contributions from industrial firms, which recognize the value of interesting young people in science.

The Nature of the Lectures

The object of the course is to show the boys and girls experiments which they read about in their textbooks or hear about in class but which they cannot be shown in a school with its limited resources. The talks are in no sense in competition with the teaching of the science masters and mistresses. Great care is taken to avoid any possibility of overlap; in fact, the courses have been planned in collaboration with a small group of science teachers who advise on their nature. We concentrate on the fundamental phenomena of science. Applications of science, recent researches, and topical events are brought in only when they serve to illustrate the fundamental laws.

It is obvious that the number of opportunities any one pupil has to come to a lecture are very restricted. Each school, getting some 40 tickets a year, can give one ticket to a large proportion of the pupils in the senior class, or can give tickets for a group of lectures to a smaller number. In any event, each pupil (during the 2 or 3 years he spends in the top form) can come on only a few occasions. But I believe that the influence of the Royal Institution lectures is out of all proportion to their number. They supply something which supplements what the pupils get at school in a very important way, just as a small quantity of a vitamin makes a vital difference to the functioning of the body. There is a vast difference between reading about some crucial scientific experiment in a textbook and seeing that experiment performed in an impressive way. It is like the difference between looking at a map of a country and paying a visit to it; one's whole outlook is altered, and the country becomes real. It is not necessary, in order to get this new viewpoint, to visit every country on the map; to travel abroad somewhere effects the psychological change. In just the same way the young people get a new and more living interest in science by seeing the great experiments performed with all the art one can muster to make them impressive.

A "Repertory Theater"

I have so far described the Royal Institution lectures without any reference to the many other centers which now arrange talks for young people. These are organized by scientific institutions, by universities, by museums, and by industry. Although the Royal Institution, with its Christmas Lectures beginning in 1826, was very early in the movement, it is now only one of many bodies which cater to this recognized need. The justification for the present account must be certain unique features which I believe the Royal Institution's lectures to have.

I have used the description "repertory theater" because the lectures for the young people are like a set of plays, which the actors and assistants are trained to perform as part of a repertory. Each lecture has a "run" during which it is given a number of times. The properties for it are stored and brought out again for another run, generally in a 3-year cycle because in that time the school population changes. In the interval between the runs, any new experiments which suggest themselves can be tried out and developed, and new equipment can be acquired.

At present there are about 30 standard lectures in the repertory, including three on electricity, one on magnetism, three on properties of matter, three on waves and vibrations, and corresponding series in chemistry and biology. These lectures are given by the full-time and part-time members of the Royal Institution staff. In addition, special talks are given from time to time by lecturers from other institutions.

There are advantages in the repertory scheme which make it a very efficient one. The development of a demonstration experiment is often a lengthy affair. Even when it appears to be simple, it is surprising how many snags one encounters, and how many tricks of technique have to be learned. An experiment which takes a minute or two to show in the lecture room may take weeks or months of patient investigation before it runs smoothly. To rig up all the experiments from scratch for a new lecture is a formidable task. Experience shows that it can easily demand experts' time measured in many months. On the other hand, once an experiment has been thrashed out, the essential gear can be stored, with notes on how to set it up and with detailed "tips" on how to make it work. It is well worth while to put time and money into a demonstration when it is used again and again.

In the second place, it is a great saving to repeat the lecture a number of times consecutively as in a short run of a play, of course to a different audience each time. The one setting up of the apparatus serves for the whole series. One point has particularly impressed me about such a run. It might be thought that it would be tedious for the lecturer to repeat the same talk day after day, but my experience has been exactly the reverse. How often, after one has given a lecture, does one profoundly wish for a chance to give it all over again with corrections of one's mistakes? A series provides this opportunity for both the lecturer and the assistants. Weak features of the experiments can be put right, one can eliminate parts of the talk which clearly went across badly and dwell longer on the parts which went well, the drill can be perfected, and above all one can improve the timing. I have often felt I am being a showman when I take advantage of my experience as to what stirs interest or arouses pleasure. But I think it is fair to use such knowledge to the full, because the purpose is to make a lasting impression on the audience by holding its attention.

There is another point about these series of lectures which has much impressed me. When lecturing to a group of pupils such as the 6th-form science classes, the audience is homogeneous, and this is an unusual situation for the lecturer. Generally an audience is composed of old and young, scientific and nonscientific, clever and less clever. The lecturer has to make a compromise in trying to give everyone something. It is most dramatic to lecture to an audience in which all the members are the same age, all are about equally clever, and all have had the same background of school teaching. A point either is made with complete success or it falls completely flat, and one soon finds out which. The talk can be tailored in a way which is impossible with a mixed audience.

The lecture technician and his staff of assistants have the setting up of the experiments as their main duty; this experience makes them very clever in this art, and at using the lecture room equipment such as closed-circuit television, magnetic blackboards, overhead projection, matched lanterns for double projection, and motion-picture projection. They must be backed by a good preparation room, ample store rooms, and the services of a workshop.

To sum up, the more one concentrates on an organization whose main function is to present a continuous series of lectures to young people, rather than an occasional series undertaken as an extra to other activities, the more one can streamline the organization with a great increase in efficiency and improvement in quality. The less also is the strain on the lecturer. If a highly specialized staff prepares the demonstrations for him and can be counted on to see that all goes smoothly in the lecture, his work is much lighter. He is like a surgeon entering an operating theater when skilled assistants have made all ready for him and he can concentrate on his expert task.

The simplifying of the lecturer's task is very important. Outstandingly good lecturers are generally busy people and reluctant to take on anything which makes large demands on their time. The really good ones with a gift for talking to young people are few, and every possible aid must be given them in order to secure their help. They are people who can project themselves into the minds of the audience, who can in fact be at the same time both audience and speaker and sense the effect on their listeners of what they are saying. They have to be able to ask themselves "How did I think when I was 17 years old, what points puzzled me, what explanation satisfied me?" It is astonishing how many great scientists are unable to project themselves in this way and quite fail to give a good talk to the young. On the other hand, by search and trial one can find the gifted few who possess the art.

Science Centers

I am convinced that organizations of this kind, devoted to giving scientific talks to young people and specially planned for that purpose, would be of the very greatest benefit in increasing the scientific potential of a country. They can only function in places where there is a concentration of population sufficient to give them continuous use, but this concentration need not be very great, because the school population is so large. The main part is that the more such organizations are planned for the special function the greater is their efficiency, and the more continuously they can be used the less is the cost in time and money needed for creating one more enthusiastic devotee of science.

CURRENT PROBLEMS IN RESEARCH

Vertical Density Currents

These currents seem to carry particles downward much more rapidly than settling according to Stokes's law.

W. H. Bradley

Fritz Nipkow's classic study (*1*) of the bottom deposits of Zürichsee established the fact that, in certain lime-rich, eutrophic lakes that have a hypolimnion, well-defined and highly characteristic annual layers, or varves, form. Indeed, Nipkov explained in a most satisfying manner everything about the formation of these varves except how the very-slow-settling constituents could have reached the bottom (at depths of 100 to 140 m) in the same year in which they were produced in the surface waters. If the particles settled in accordance with Stokes's law, even the very small calcite particles (2 μ in diameter), which crystallized out from the surface waters, would have required 1.3 years to reach bottom. How much more slowly the frustules of the delicate diatom *Stephanodiscus hantzschii* Grunow might have settled we can only guess. Yet Nipkow shows that a short burst of growth of this diatom is represented within the varve of the year in which the burst occurred by a thin, clearly defined layer characterized by these frustules.

We must conclude that most of the particles in the Zürichsee varves could not have reached the bottom of that deep lake as discrete individuals settling in accordance with Stokes's law. Some other mechanism is necessary to account for the facts Nipkow observed.

One possible mechanism to account for the observed proper sequential order in bottom sediments of microscopic constituents whose individual settling rates differ by several orders of magnitude is that of vertical density currents. The concept of vertical density currents can most conveniently be examined by considering the behavior of calcite particles generated in the surface waters of Zürichsee. These particles originate in the surface waters of the lake (*2*) in two ways: (i) in, or on, the mucilage of planktonic algae through marked decrease in the carbon dioxide pressure by photosynthesis of the algae, and (ii) in the water itself through decrease in the carbon dioxide pressure by progressive warming of the surface water. By either means, in normal years, such vast numbers of calcite particles are formed that the surface waters become milky. Inasmuch as these particles are created in the surface water and are numerous enough to make it turbid, it occurred to me that if, by some means, the particles in any part of the surface water are brought closer together, they and the water containing them will together be

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